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PBX 9502 Multimode Damage Accumulation Cycles-to-Failure Study

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Disclaimer

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Introduction

In FY13, we performed a detailed cycles-to-failure study of PBX 9502 using 3-point bend specimens. In that study we examined the effect of temperature and cyclic frequency on the failure behavior of PBX 9502. We identified cycles-to-failure curves for samples tested at -20˚C, ~19˚C and 50˚C and at cyclic frequencies of 0.0001 up to 1-Hz. We also did cyclic conditioning of parts in an effort to establish damage accumulation criteria that could then be used in predictive models. As follow-on to that work, in FY14 we have added multimode cycles-to-failure to our test suite.

Work this year re-established the baseline cycles-to-failure behavior of the PBX 9502 material tested round ~19˚C at 1-Hz and also looked at damage accumulation under a multimode loading environment. This fresh baseline development was performed to remove any time related or test rig related variables. The multimode loading was done because real-world applications are not mono-modal and we desire for our predictive capability to be robust and include more complex, realistic scenarios.

In the following sections we briefly describe the test setup, we provide a summary of the new baseline results and we show the multimode cycles-to-failure data and how it compares to the mono-modal test data.

Experimental Details

The specimens tested in this series were square cross-section beams that were made from Holston-manufactured virgin PBX 9502 lot HOL8H891-009. The beams were machined at Site 300 from a billet that was iso-statically pressed at Pantex in 2011. The samples were machined into beams in three groups at different times. The parts came from three different locations from within the same billet.

The beams used for this study were 1 cm (0.394 inches) square in cross-section by 5.5 cm (2.16 inches) long, with a notch depth, a_0, that was typically 0.55 mm (0.022 inches) deep. The notches in the beams were made using a Well diamond wire saw, with a kerf of about 300 μm.

An Instron ElectroPuls E3000 load frame with a 3-point bend fixture and a top mounted 1-kN load cell were used to perform all tests in the series. Figure 1 shows the commercial test frame on the left and a zoomed in view of a notched PBX 9502 sample in place on the 3-point bend fixture on the right.

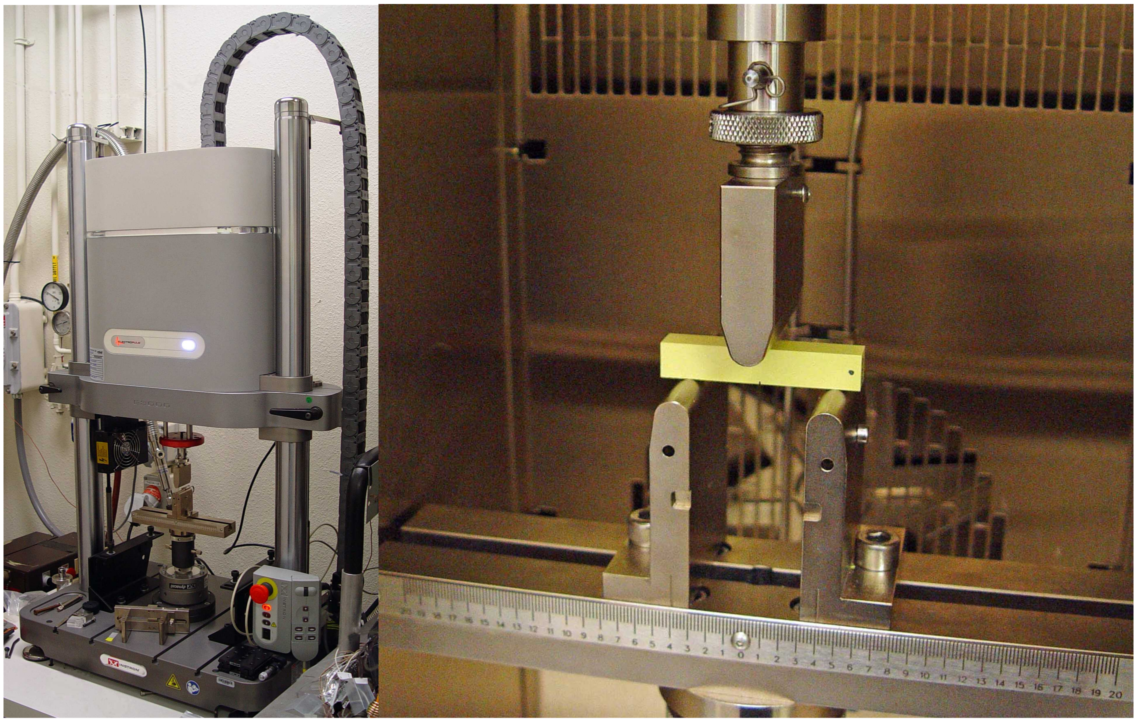

Figure 1. Our Instron ElectroPuls E3000 test frame is shown above on the left and a magnified view of our 3-point bend fixture with a notched PBX 9502 specimen in place within an environmental chamber is shown on the right.

To establish a fresh baseline of cycles-to failure to peak load curve we cycled samples to failure at several loading levels, where each loading level represented a percentage of the average maximum failure load for the given temperature (~19˚C) and loading rate. The loading waveform was sinusoidal with a frequency of 1-Hz. Note that in cycling, we did not unload completely, but maintained a 10-N lower load limit, so that the loading pin (the upper pin in the three point bend setup) never lost contact with the sample. Thus, for example, if the upper load level was to be 120-N, the system was programmed to cycle between 120-N and 10-N, so that the amplitude of the sinusoidal loading wave was 55-N.

Figure 2 shows the old baseline curve in green and the new baseline curve in red, both with log fits. The new group sustained more cycles-to-failure at each of the peak load levels. Taken as a whole, this stronger behavior is evident, as the whole curve has been shifted up. In addition to the new baseline curve, Figure 2 shows the data points for the multimode tests. Four multimode tests were run in which a sample endured 10 cycles at 117-N then one cycle at 131-N at a test temperature of ~19˚C and a loading frequency of 1-Hz. This eleven-cycle pattern was repeated until the sample failed. After failure, the data were evaluated and a point was put on the plot for the number of cycles experienced at each load level. For each multimode test, there are two points on the plot, one point at x-cycles at 131-N and another point at x times 10-cycles at 117-N.

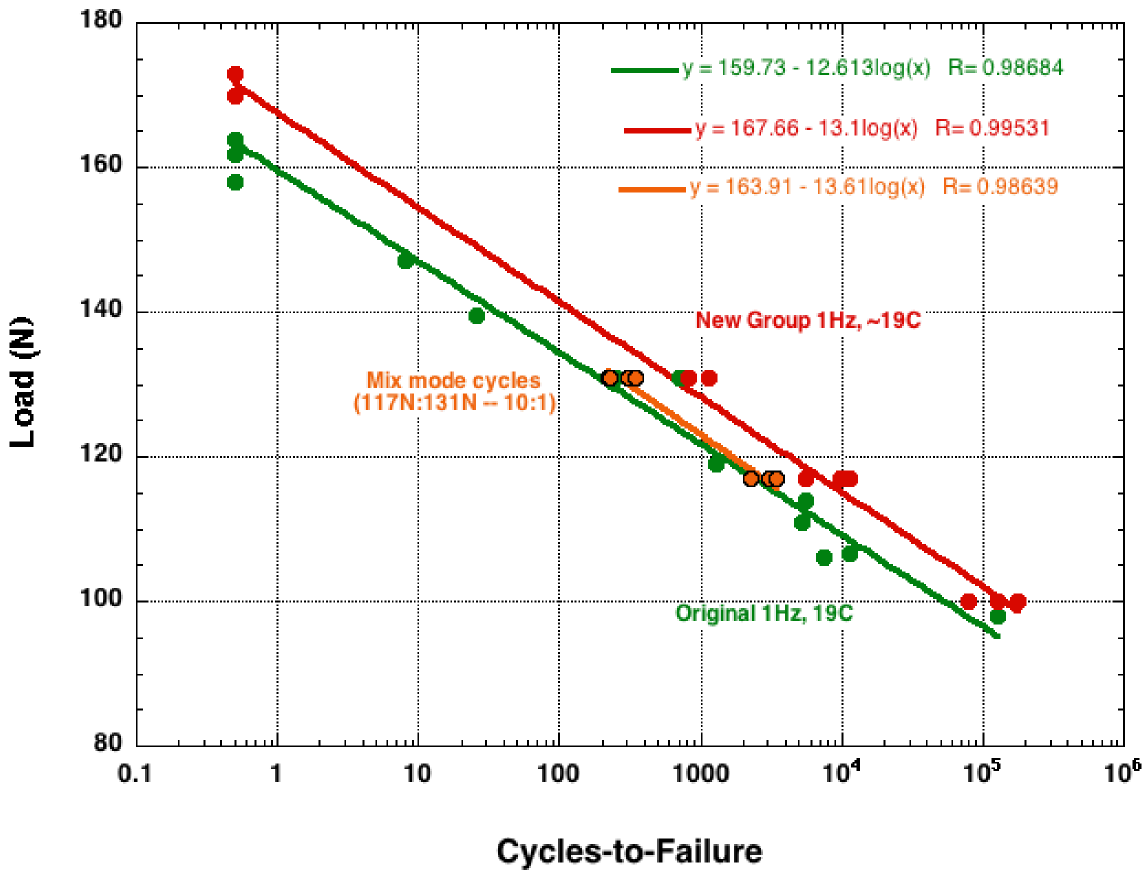

Figure 2. PBX 9502, 3-point bend baseline cycles-to-failure data for the old group (green) and the new group (red) of specimens, tested at T=~19˚C and a loading frequency of 1-Hz. The orange data points represent the four multimode tests run on samples from the same group as the New Group shown above. For the same multimode test, there are two points on the plot representing both the higher load cycles at 131-N and the lower level cycles at 117-N. Both are plotted to show how they compare to the baseline curves.

The data points shown in Figure 2 are tabulated below in Table 1. During this FY there were four new baseline tests performed at each load level (117-N and 131-N). The average cycles-to-failure for the 117-N peak load tests was 8,080-cycles. The mono-modal tests at 131-N lasted 828-cycles on average. The average number of 117-N load cycles experienced during the multimode tests was 2,761 and the average of the 131-N peak load cycles experienced was 276. In both cases, the number of cycles used in the multi-mode tests was about 33% of the cycles experienced during the newer mono-modal tests. The reduced cycle-life is demonstrative of damage accumulation. If the full baseline dataset was used, including both the new group and the old group, the amount of cycles experienced during the multi-mode tests is closer to 40% of the average experienced in the multi-mode tests. This series has clearly demonstrated that there is some additive effect of cycles with various amplitudes. To work through the details many more tests will need to be run to sort out the many variables.

Table 1. Data summary for mono-modal tests to failure for the group of samples tested this FY at 117-N and 131-N. Also, the cycles-to-failure data for the multimodal loading condition as well as the % of the mono-modal cycles-to-failure data.

Mono-modal Tests to Failure

Load (N)	Cycles to Failure	Comments
117	9716	Recent Test
117	11421	Recent Test
117	5480	Recent Test
117	5704	Recent Test
	8080	Average 117N
131	1154	Recent Test
131	311	Recent Test
131	822	Recent Test
131	1025	Recent Test
	828	Average 131N

Multi-modal Loading

	117-N	131-N	% of 117N Avg.	% of 131N Avg.
Cycles	2249	224	28	27
Cycles	3045	304	38	37
Cycles	3494	349	43	42
Cycles	2254	225	28	27
Avg.	**2761**	**276**	**34**	**33**